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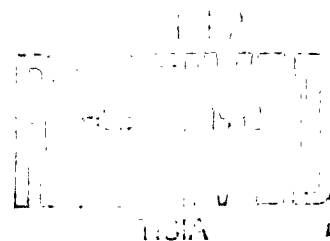
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MANUFACTURING RESEARCH BRAZING ALLOYS,  
HIGH TEMPERATURE OPERATING, DEVELOPMENT OF

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**A DIVISION OF GENERAL DYNAMICS CORPORATION  
(FORT WORTH)**

Department 6  
FWP 1999-9-54

**MODEL 9024**

DATE 17 February 1959

**TITLE**

# PLANTING AND RESEARCH

TEACHING ALGEBRA, HIGH RESISTANCE OPERATING, INVESTMENT OF

**SUBMITTED UNDER**

MANUFACTURING RESERVE WORK ORDER #12-01-100

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## REVISIONS

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## MANUFACTURING RESEARCH

### BRAZING ALLOYS, HIGH TEMPERATURE OPERATING, DEVELOPMENT OF

#### INTRODUCTION:

With the higher operating temperatures that will be encountered in future aircraft, the requirements for strength and oxidation resistance at temperature will eliminate the use of the silver-base brazing alloys in sandwich panel construction. It will be necessary to select brazing alloys that will be compatible with the base metals selected for use at the desired service temperatures.

This program was conducted to determine what brazing alloys have the desirable brazing characteristics with base metals for use at service temperatures ranging from 1000 to 1600 F. As all the base-metal members used in the construction of sandwich panels will be of thin gage material, the reactions that take place between the brazing alloy and the base metal will be of prime importance.

#### SUMMARY:

Preliminary experiments were conducted to determine the general flow, wetting, and fillet forming characteristics of 20 brazing alloys on six base-metal alloys, with core sections of 17-7 PH stainless steel and M 252 alloy. Additional tests were conducted on those base metal-brazing alloy combinations that looked promising to determine their resistance to salt-spray corrosion and 1250 F oxidation. Metallographic examinations were made to determine the extent of alloying of the brazing alloy with the base-metal and the extent of diffusion of the brazing alloy constituents into the base metal. From the results of this work, the combinations which appeared to have the most desirable properties were tested to determine the lap-shear strength at room temperature.

The results of the tests conducted indicated that the following brazing alloy-base metal combinations merit further investigation.

<u>Base Metal</u>	<u>Brazing Alloy</u>
PH 15-7 No 420 H	2414, 56.2Ni, 9.80cr, 10Si Cobalt 42712 J 8102
Fillet 300	2414, 56.2Ni, 9.80cr, 10Si Aluminum EX1 2414, 56.2Ni, 9.80cr, 10Si J 8102

# CONVAIR

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DATE 2-17-59

## Base Metal

Inconel 700  
M 252

GE 1610

## Brazing Alloy

Coast 4271E  
J 8205  
24Pd, 56.2Ni, 9.8Cr, 10Si  
J 8205  
J 8101  
J 8100  
Solabraz IX1

## MANUFACTURING RESEARCH

### BRAZING ALLOYS, HIGH TEMPERATURE OPERATING, DEVELOPMENT OF

#### OBJECT:

The object of this investigation was to study the brazing characteristics of some structural alloys, known to possess high strength at elevated temperature, when joined with various brazing compositions. A main purpose was to determine the value of brazing alloys recommended for service at high temperatures. Based on the results obtained, the ultimate objective was to select those brazing alloy-base metal combinations which appeared to be the most promising for use in sandwich panel construction.

#### DESCRIPTION OF SPECIMENS:

Six base-metal alloys were selected for use in this investigation. They were: 422 M, PH 15-7 Mo, Udimet 500, Inconel 700, M 252, and GE 1610 (Rene 41). Typical analyses of these alloys are given in Table I.

Twenty brazing alloys were investigated. Two were: Vacuum-melted nickel-manganese and 64% silver, 33% palladium, 3% manganese, both of which were furnished as foil, 0.002" thick. Sixteen of the brazing alloys were obtained in powder form. They were: Coast 52, 59, 4271E, and 132E; Solabraz H, IX1 and NX1; General Electric J 8100, J 8101, J 8102, J 8205, J 8300, and J 8400; 24% palladium, 36.2% nickel, 9.8% chromium, and 10% silicon; and 60% palladium and 40% nickel. Two nickel-base alloys were obtained in foil form made by impregnating the brazing alloy powder with an organic binder. These were: Microbraz 50 and an unidentified Coast alloy.

Specimens to determine the comparative wetting, flow, and fillet forming ability of the brazing alloys were made by wiring a section of 17-7 PH stainless steel honeycomb core to a 1" x 2" piece of one of the base metals, to form a tee as shown in Figure 1. When foil of M 252 was subsequently obtained, this series of experiments was repeated, using honeycomb core specimens made in the laboratory from the M 252 foil.

Small tee specimens, as shown in Figure 2, were brazed for metallographic examination and oxidation-resistance tests. Specimens for salt-spray exposure tests were made by brazing a measured quantity of brazing alloy onto 1" x 2" coupons of the base metals. Specimens for shear-strength determinations were made as shown in Figure 3. Due to difficulties encountered in



machining the brazed specimens to conform to the tentative standard of the American Welding Society, as shown in Figure 4, the specimens were wet ground to the configuration shown in Figure 5.

#### PROCEDURE:

The six base metals were selected on the basis of their availability, high temperature strength, ductility in the annealed condition, and resistance to oxidation and corrosion. Several of these alloys had a light surface scale when received and were cleaned by vapor blasting.

All the specimens were brazed in a tightly covered retort in a -100 F dry bulb argon atmosphere. Brazing was performed in an electrically heated furnace. The temperature was controlled by attaching a thermocouple to a specimen in each retort. Brazing cycles of 10 minutes at temperature were run simulating a practicable production brazing cycle.

Tee specimens, consisting of a piece of base metal and 17-7 PH stainless steel honeycomb core, were wired together, as shown in Figure 1. A measured quantity of brazing alloy was placed in one end cell, the same volumetric quantity being used for all the powdered alloys. The foil alloys were weighed to obtain the same approximate quantity of brazing alloy as was used with the powdered alloys. The distance flowed at the interfaces of the core and the base metal gave an indication of the flowability of the brazing alloys. The specimens also gave an indication of the comparative wetting and fillet forming characteristics. Subsequently, a series of brazements was made with all the base-metal alloys, except 422 M, using honeycomb-core sections made in the laboratory from M 252 foil. Because of the poor wetting and flow characteristics shown by the brazing alloys on all the base metals except 422 M, a sodium tetraborate flux was employed in the series using the M 252 honeycomb-core material.

Small tee specimens were brazed, consisting of two pieces of the base metals wired together as shown in Figure 2. These gave an indication of the brazing qualities of the brazing alloys. The brazed specimens, which appeared satisfactory, were cut in two; one-half was used for metallographic examination and the other half was subjected to a 100-hour oxidation-exposure test at elevated temperature. The nickel-base alloy specimens were exposed in a furnace at 1250 F, and the iron-base alloys were exposed in a furnace at 1000 F. The specimens subjected to oxidation were examined both visually and metallographically for indications of oxidation.

Corrosion specimens were prepared by brazing a small spot of brazing alloy on the respective base metals. These were subjected to a 250-hour salt-spray exposure and examined for evidence of corrosion.

Specimens for shear-strength determinations were prepared with a gap of 0.0015". Reportedly, a near-zero gap gives the best ductility when brazing with the nickel-base brazing alloys. However, to permit flow into the joints, a gap of 0.0015" was selected. The specimens were made by clamping the two pieces in place while separated by a shim, tack welding together, removing the shim, and brazing. Machining difficulties, due to the work-hardening characteristics of the base metals, caused breakage of many of the brazed specimens. This breakage was reduced by grinding the slots with a wet abrasive wheel to the configuration shown in Figure 5.

All the lap-shear specimens were tested in a 5,000 lb. Baldwin universal testing machine. The specimens were tested by loading the brazed area at the rate of 6960 psi per minute.

## RESULTS:

Tables II through VII give the brazing characteristics of the six base metals when brazed with 18 of the high-temperature brazing alloys. Acceptable brazes could not be obtained with the two alloys impregnated with an organic binder, viz., Micro-braz 50 and the unidentified Coast alloy. Also, shown in the Tables, are the generally improved brazing characteristics resulting from the use of a sodium tetraborate flux. The Tables also give the results of the 250-hour salt-spray corrosion tests, metallographic observations, and the results of attempts to braze the lap-shear specimens. It was found that all the brazing alloys which would braze with the base metals exhibited as good or better oxidation resistance than the base metals at the exposure temperatures involved. These were 1250 F for Udimet 500, Inconel 700, M 252, and GE 1610, and 1000 F for 422 M and PH 15-7 Mo.

Tables VIII through X give the shear-strength values of the most promising brazing alloys selected for each of the six base metals.

Figures 6 through 9 are photomicrographs of the joints made with brazing alloys which gave the best results. Figures 10 through 12 show three which yielded poor results, but metallographically appear good. These should be further investigated with different brazing techniques.

## DISCUSSION:

The metals under consideration for use in the temperature range 1000 to 1600 F fall in the following groups:

The iron-base martensitic alloys, containing chromium as the chief alloying addition in quantities to approximately 15%, have useful strength values to about 1000 F. Representative are 422M, Vascojet 1000, Greek Ascoloy, and 15-7 Mo.

The nickel-base alloys, alloyed chiefly with chromium to approximately 25% have outstanding strength values to as high as 1600 F. The superior strength values exhibited by some members of this group of alloys in the 1500 to 1600 F range is attributed to the presence of a gamma prime phase,  $\text{Ni}_3(\text{Al}, \text{Ti})$ , in addition to a solid-solution strengthener with a low diffusion rate, such as molybdenum or tungsten. Representative of the group are GE 1610 (Rene 41), M 252, Udimet 500, Inconel 700 and R 235. The cobalt-base alloys, with nickel and chromium as the chief alloying additions, have been superseded in favor by the nickel-base alloys due to the lack of an effective precipitation hardening system.

Judicious alloy additions and vacuum melting have extended the useful temperature range for some alloys in the above groups by as much as 100 F.

The primary effort of this investigation was directed toward the brazing qualities of the nickel-base parent alloys. Those selected were GE 1610, M 252, Udimet 500, and Inconel 700. Some work was also done on 422 M, of the iron-base martensitic group, and PH 15-7 Mo, a new precipitation hardening stainless steel having improved creep and stress rupture characteristics over the 17-7 PH stainless steel now in use. Typical compositions of the six alloys investigated are given in Table I.

Twenty brazing alloys were selected for use in this investigation, chiefly upon the recommendations of the various brazing alloy manufacturers. With the exception of three palladium-base alloys, these were all nickel-base alloys having brazing temperatures in the 1800 to 2275 F range. The nickel-base brazing alloys contain various combinations of chromium, manganese, silicon, boron, iron, or molybdenum. The purpose of

these additions is to lower the melting point of the nickel, improve oxidation resistance, and lessen the tendency to solution attack on the base metal. All but one of the nickel-base brazing alloys were in the form of a fine powder. These cannot be obtained as foil.

It was observed that many of the brazed joints were quite brittle. In the extreme cases, this condition precluded testing for strength. Metallographic examination revealed two causes of brittleness, other than the brazing alloy itself. Some specimens appeared clean but exhibited cracks in the brazing alloy. These were attributed in some cases to brittle intermetallics formed with the base metal during brazing. Other specimens contained excessive inclusions within the brazing alloy. These usually appeared as an almost continuous line in the braze metal next to the parent metal. Variations in shear strength and in brittle behavior found in some of the brazing alloys were probably due to this cause. Further work may eliminate the low strength joints caused by the inclusions.

It was found that, unlike the silver-base brazing alloys, the nickel-base and palladium-base brazing alloys attack the base metals to varying degrees at the brazing temperature. The degree of attack depends upon both the temperature reached above the melting point of the brazing alloy and the time that the base metal is in contact with the molten brazing alloy. For this reason, the brazing operations were conducted on a comparative basis. A brazing cycle of 10 minutes at the brazing temperature was maintained for all the alloys, simulating a practical production brazing cycle.

The screening tests performed by brazing the base metals with the various brazing alloys eliminated a majority of the latter from further consideration. This was due chiefly to either poor quality of braze, poor salt-spray corrosion resistance, or excessive solution attack of the base metals.

The iron-base 12% chromium alloy, 422 M, brazed better with the high-temperature brazing alloys than the other base metals. Wetting was generally good without flux. Brazing was difficult with the four nickel-base parent alloys, all of which contained considerable aluminum and titanium. The use of a mild flux, sodium tetraborate, improved the wetting characteristics of the brazing alloys on this group of metals. Of the alloys tested, Udimet 500 and Inconel 700 appear to be the most difficult to braze. These alloys form a dark tenacious surface film, even when brazed in the presence of the other alloys which had a bright metallic surface after brazing.

The iron-base martensitic alloy, 422 M, was found to give the best results when brazed with the Coast alloy 4271E, having shear strengths of from 59,530 to 72,980 psi. This base alloy was susceptible to crevice corrosion when brazed with many of the high-temperature brazing alloys.

No high temperature brazing alloy was found that satisfactorily brazed PH 15-7 Mo stainless steel. The brazing characteristics were either poor or the joint was susceptible to crevice corrosion.

The nickel-base alloy, Inconel 700, brazed best with Coast 4271E and the sodium tetraborate flux, giving shear strengths of up to 57,410 psi. Udimet 500 brazed best with Solabraz IX1 and the sodium tetraborate flux, with shear strengths of up to 52,380 psi. High-temperature brazed joints on both metals appear to be generally poor because of inclusions. Better techniques may improve the brazing characteristics of both metals. M 252 and GE 1610 brazed best with the General Electric alloy J 8205 and the sodium tetraborate flux. Shear strength values of 50,530 psi were obtained on the M 252 and 43,930 psi on the GE 1610.

The photomicrographs, Figures 6 through 9, show the joints obtained when the four nickel-base metals were brazed with the brazing alloys which gave the best results.

Figure 10 shows 422 M brazed with the Microbraz 50 organic bonded foil. Although poor braze results were obtained, the metallographic examination led to the belief that without the organic binder, Microbraz 50 may give good results on the nickel-base alloys.

Figure 11 shows M 252 brazed with a 24% palladium, 56.2% nickel, 9.6% chrome and 10% silicon brazing alloy. The braze, with a shear strength of 39,000 psi, shows much less attack on the base metal than the stronger brazing alloys, and should be included in any future investigations.

Figure 12 shows GE 1610 brazed with J 8100. The latter alloy did not braze well and gave a low strength value, but the metallographic appearance suggests that further investigation with modified brazing techniques is warranted.

Metals having good strength properties in the temperature range of 1000 F to 1600 F are difficult to braze with the high melting point nickel-base and palladium-base brazing alloys without a flux.

The nickel-base parent metals which showed the best strength values at high temperatures contain titanium and aluminum in amounts to 3% of each. The oxides formed by these additions are very difficult to remove and interfere with wetting. When brazed with a sodium tetraborate flux, some of the brazing alloy-base metal combinations exhibited very good room-temperature shear strength, along with other properties favorable to the production of brazed structures.

In general, the nickel-base brazing alloys give better results than the palladium-base alloys. The chief drawbacks to the use of most of the nickel-base brazing alloys was their powdered condition, the brittle nature of the brazed joints, and the tendency to dissolve and penetrate the parent metals. Some of these disadvantages will probably be lessened through development of an effective inorganic or metallic binder for the powdered alloys and improved brazing techniques.

The full extent of the effect of the brazing characteristics of the more promising high-temperature brazing alloys on light weight brazed structures must await the availability of the metals in thin gages.

## CONCLUSIONS:

The most promising brazing alloy-base metal combinations investigated for use at 1000 F and higher temperatures are listed below. These appear to merit further investigation.

<u>Base Metal</u>	<u>Brazing Alloy</u>
PH 15-7 Mo	24Pd, 56.2Ni, 9.8Cr, 10Si
422 M	Coast 4271E J 8102 24Pd, 56.2Ni, 9.8Cr, 10Si
Udimet 500	Solabraz IX1 24Pd, 56.2Ni, 9.8Cr, 10Si J 8102
Inconel 700	Coast 4271E
M 252	J 8205 24Pd, 56.2Ni, 9.8Cr, 10Si J 8101
GE 1610 (Rene 41)	J 8205 J 8101 J 8100 Solabraz IX1

## R E F E R E N C E S

F. M. Miller et al., "Development of Brazing Alloys for Joining Heat-Resistant Alloys," WADC TR-55-213, July 1955, 66 pp.

W. E. Russell & J. P. Wisner, "An Investigation of High-Temperature Vacuum and Hydrogen Furnace Brazing," NACA TN-3932, March 1957.

E. G. Huschke, Jr. & G. S. Hoppin, III, "High-Temperature Vacuum Brazing of Jet Engine Materials," Welding Journal, Vol. 37, No. 5, 1958, pp. 233S - 240S.

L. P. Jahnke & R. G. Frank, "High-Temperature Metallurgy Today," Metal Progress, Vol. 74, No. 6, 1958, pp. 86-91.

## TABULATION SHEET

Table I.  
Typical Compositions Of Six Alloys Having  
High Temperature Strength Used For Brazing Studies

Alloy	C.	Ni.	Cr.	Co.	Mo.	Fe.	Ti.	Al.	W.	Mn.	Si.	P.	S.	B.	V.
422M	.27		12.		2.23	83.23			1.75						.50
15-7 Mo	.09	7.	15.		2.25	73.		1.15		1.0	1.0	.04			
Udimet 500	.10	53.	17.5	16.5	4.	2.	3.	3.							
Inconel 700	.08	44.	16.	29.	3.	1.5	2.3	2.5							
M252	.15	53.5	19.	10.	9.5	3.	2.5	1.0							
GE 1610	.09	50.	19.	11.	10.	5.	3.	1.5		.50	.50			.01	















## TABULATION SHEET

Table VIII  
High Temperature Brazing Alloys -  
Room Temperature Shear Strength Values

Brazing Alloy	Base Metal	Spec. No.	Dr. Temp. °F	Time	Flux	Atmos.	Gr. Thick. In.	Gr. Area	Load, Lbs.	Shear Stress In B.M.
Solabraz IX1	Inc. 740	S9	1950	10 Min	Brazing	Agass	.1451	.0455	272	27055 9890
Solabraz H		S12	1900				.1252	.058	412	56745 14210
		S15					.1189	.055	358	54740 13010
Coast 42715		S6	1900				.1228	.056	395	57410 14100
		S13					.1067	.052	183	32970 7040
JB101	G.E. 1610	R6	2040				.1453	.071	368	35725 10360 Bent.
		R7					.1248	.070	323	36955 9230
		R11					.1421	.072	375	36765 10410
JB100		R9	2120				.1311	.074	233	24020 6300
		R5	2120				.1386	.066	402	43930 12180
		R10					.0976	.070	257	37625 7340
		R18					.1252	.068	367	43175 10790
Ni Mo.		R16	1900				.1465	.068	434	43570 12760
Shear Stress of Joint = Load, lbs.										
Joint Area, Sq. In.										
Stress in Base Metal Cross Section, P.S.I. = Load, lbs.										
B.M. Area = Thickness of Specimen x Width of B.M. at Cut.										

Table IX  
High Temperature Brazing Alloys—  
Room Temperature Shear Strength Values

Brazing Alloy	Base Metal	Spec. No.	Br. Temp. °F.	Time @ Temp.	Flux	Atmos.	Length of Brazing Joint	Thick. of Joints	Br. Area	Load, LBS.	Shear Stress, in B.M.	Stress in B.M.
Coast #52 Sp.	422M	M3	1850	10 Min	Borax	Argon	.1223	.057	.007	479	68,430	16,800
J8102		M6	2175				.1201	.051	.0061	252	41175	9,880
		M10					.1262	.053	.0072	470	65095	17,735
		M13					.1209	.051	.0062	435	70615	17,060
		M15					.1331	.052	.0069	478	69075	18,380
		M22					.1370	.051	.007	410	58655	16,080
		M26					.1264	.053	.0067	519	77460	19,580
24Pd, 56.2 Ni, 9.0Cr, 10.5 Si.		M9	1900				.1433	.051	.0073	359	49110	14,080
		M18					.1685	.051	.0086	285	33175	11,170
		M20					.1075	.053	.0057	215	37715	8,110
		M21					.1256	.052	.0065	275	42110	10,570
Coast 4271E		M4	1900				.1390	.051	.0071	427	60225	16,700
		M5					.1272	.054	.0069	409	59530	15,140
		M11					.1224	.051	.0062	428	68590	16,780
		M12					.1354	.053	.0072	524	72980	19,770
		M23					.1343	.057	.0077	482	63005	16,910
		M25					.1299	.057	.0074	520	70175	18,240
Solabraz NX1	15-7M6	J5	2100				.0917	.066	.0061	176	29090	5330 Bent
		J6					.1154	.063	.0073	186	25385	5900
		J9					.1173	.065	.0076	183	23980	5630 Bent
Coast #59		J7	2175				.1453	.061	.0089	224	25280	7340
		J8					.1339	.063	.0084	326	38670	10,350 Bent
		J10					.1205	.063	.0076	288	37945	9,140 Bent



# TABULATION SHEET

## High Temperature Brazing Alloys-

High Temperature Brazing Alloys -  
Room Temperature Shear Strength Values:

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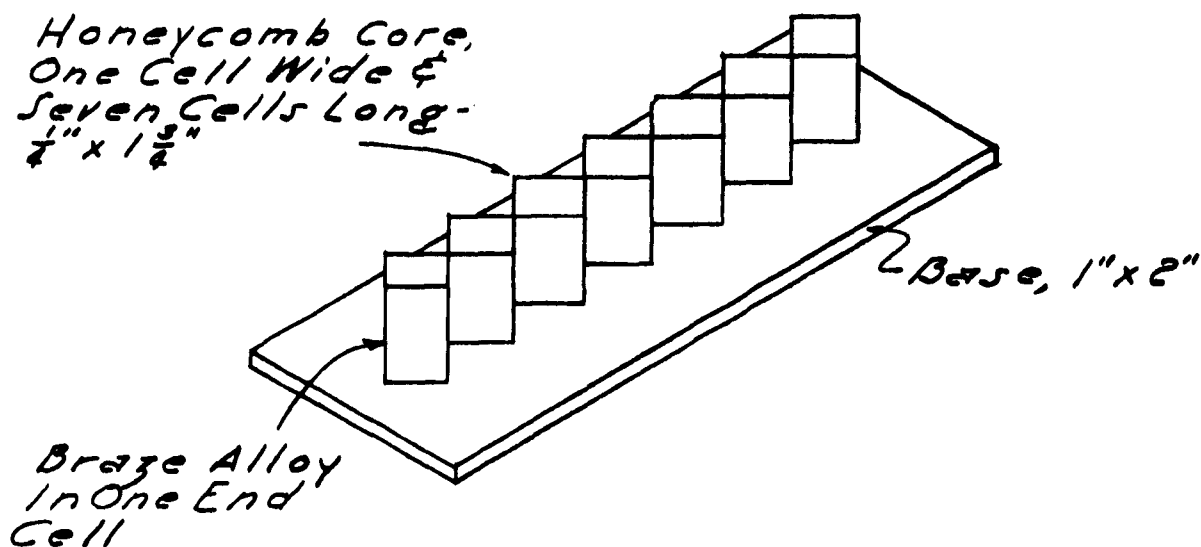


Figure 1.  
Tee Specimen For Flow, Wetting And  
Filletting Studies

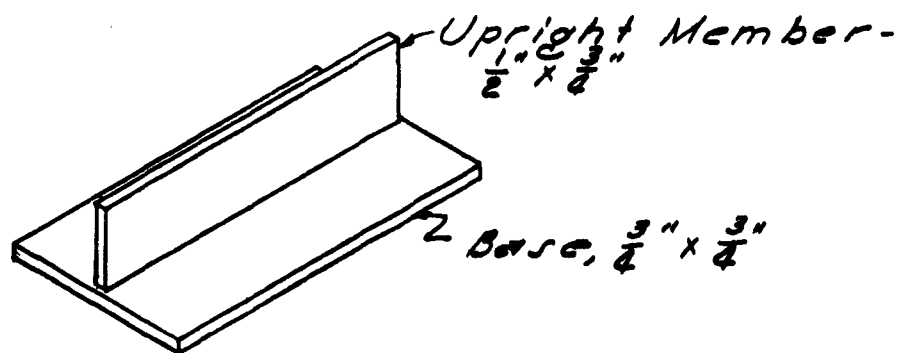


Figure 2.  
Brazed Tee Specimen For Metallographic  
And Oxidation Resistance Studies

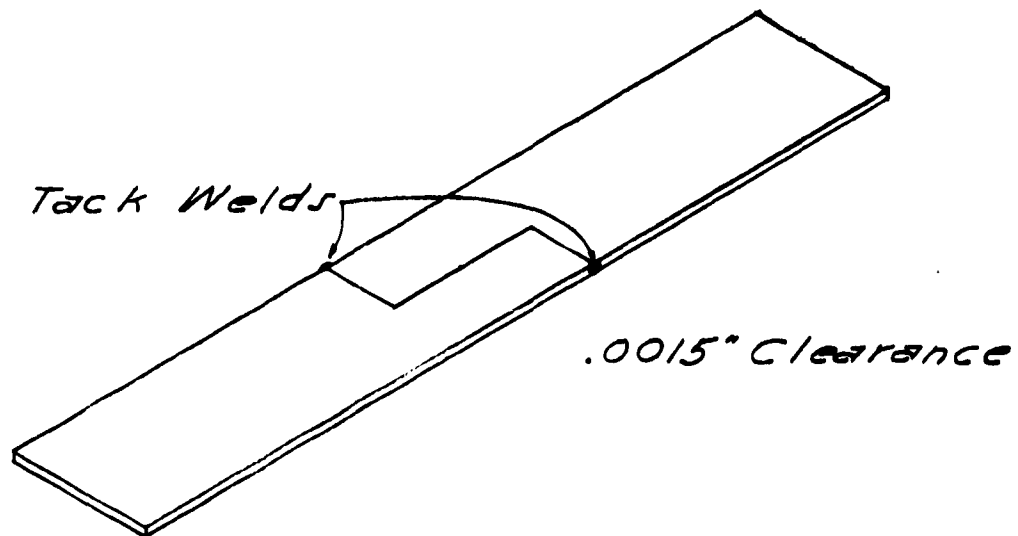


Figure 3.  
*Shear Strength Specimen Ready For Brazing.*

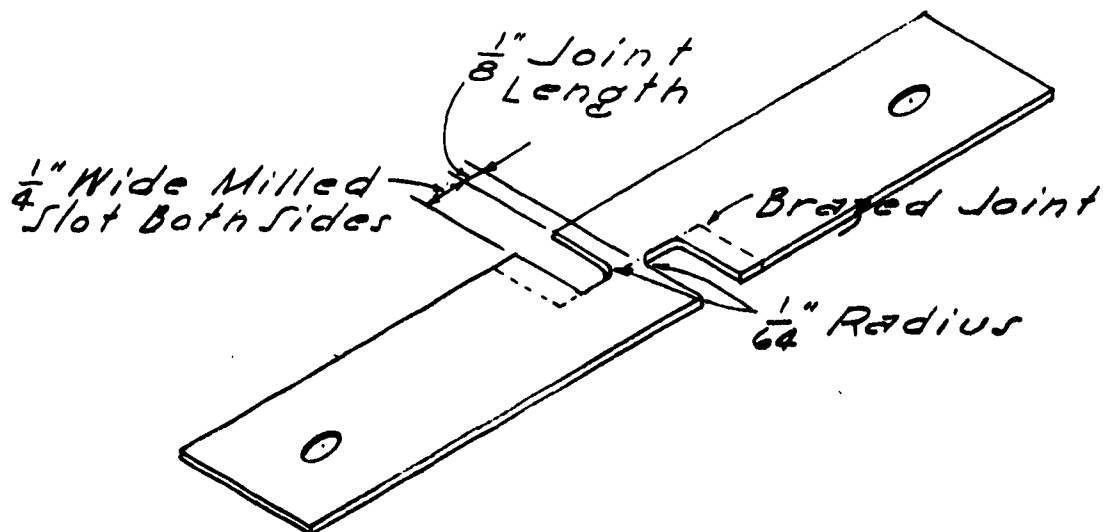


Figure 4.  
*Brazed Shear Strength Specimen  
Machined To Tentative A.W.S. Spec.*

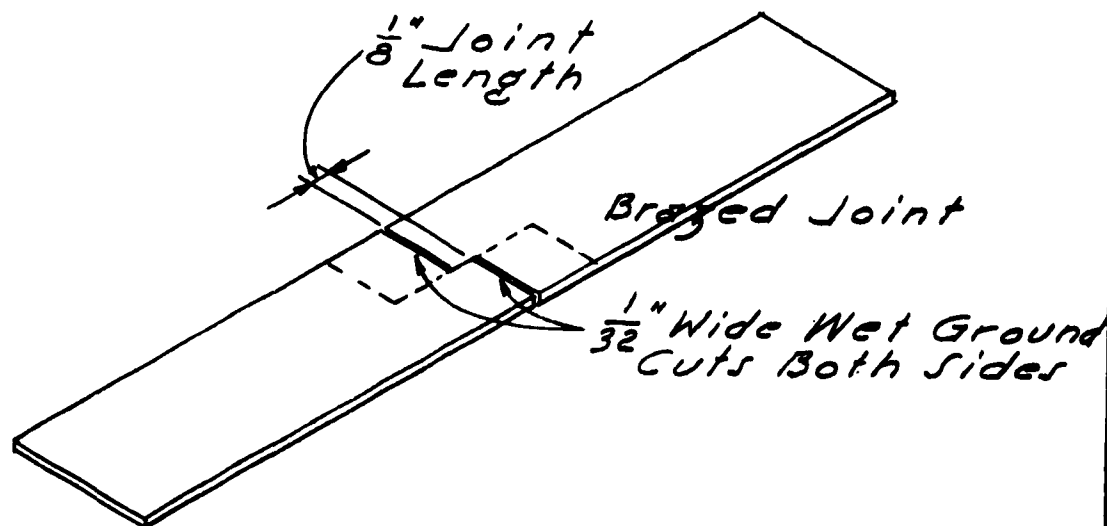
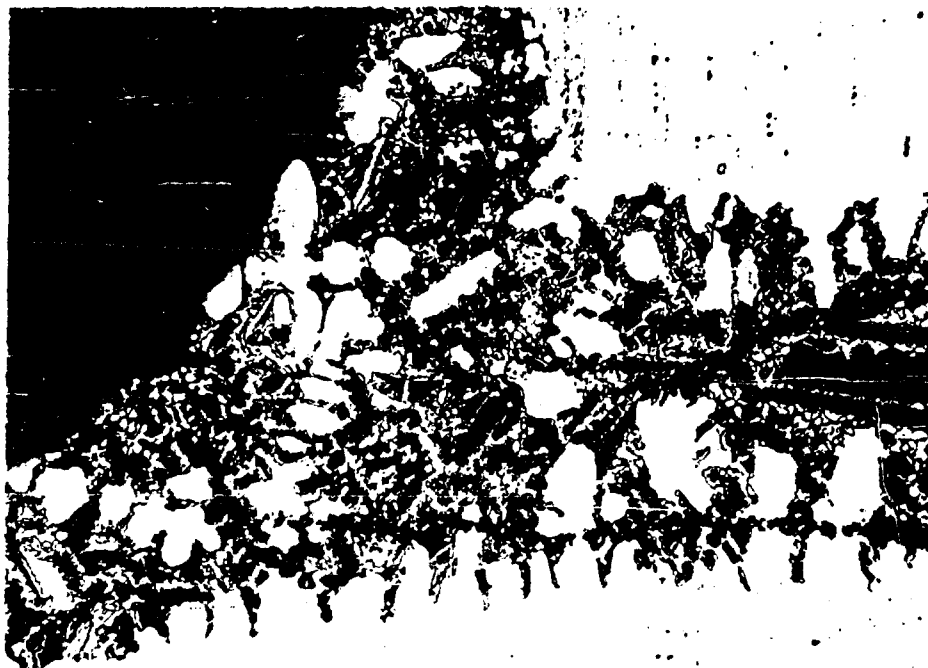


Figure 5.  
*Brazed Shear Strength Specimen  
As Altered For Test.*



Mag. 250X

Eten - Electrolytic Oxalic Acid

Udimet 500 brazed with Solabraz IX1 brazing alloy.

Figure 6

Best Available Copy

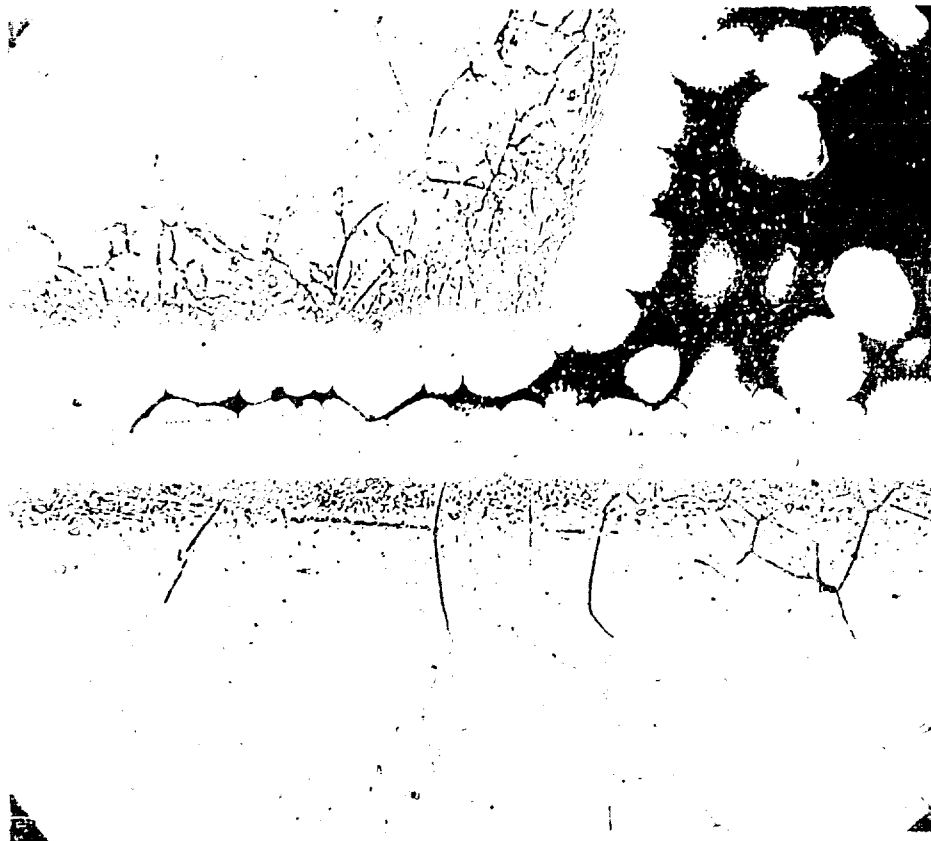


Mag. 250X

Eten. - Electrolytic Oxalic Acid

Inconel 700 brazed with Coast 4271E brazing alloy.

Figure 7

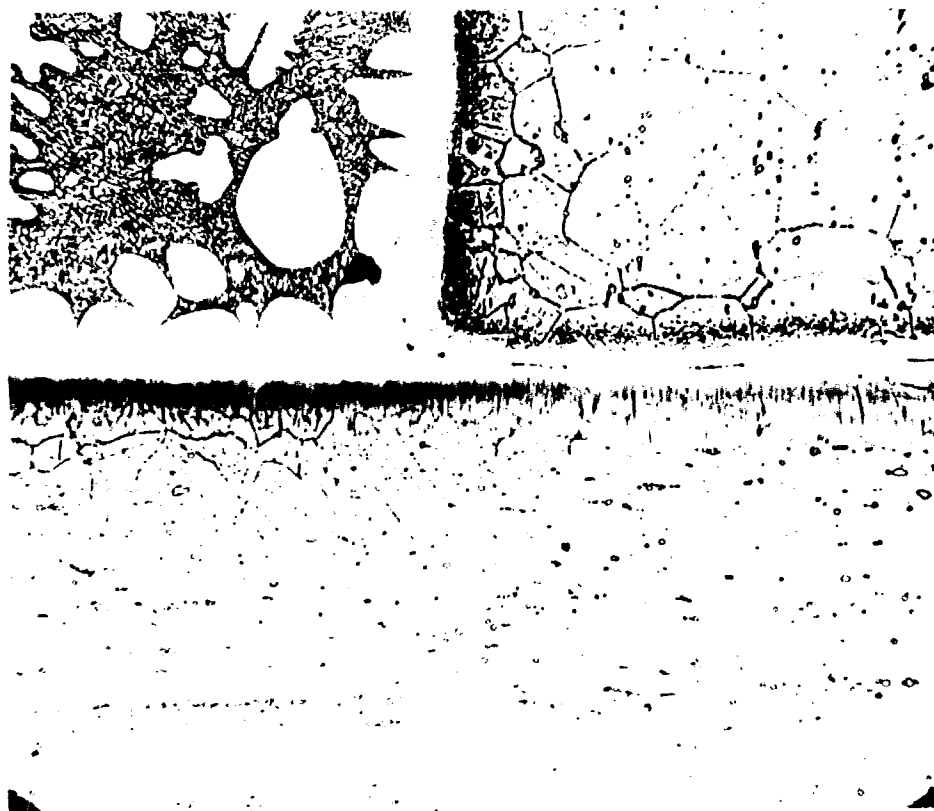


Mag. 250X Electrolytic Oxide on

in 252 brazed with J 6205 brazing alloy.

Figure 6

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Mag. 250X

Electrolitic Oxalic Acid

GE 1610 (Rene 41) brazed with J 8205 brazing alloy.

Figure 9

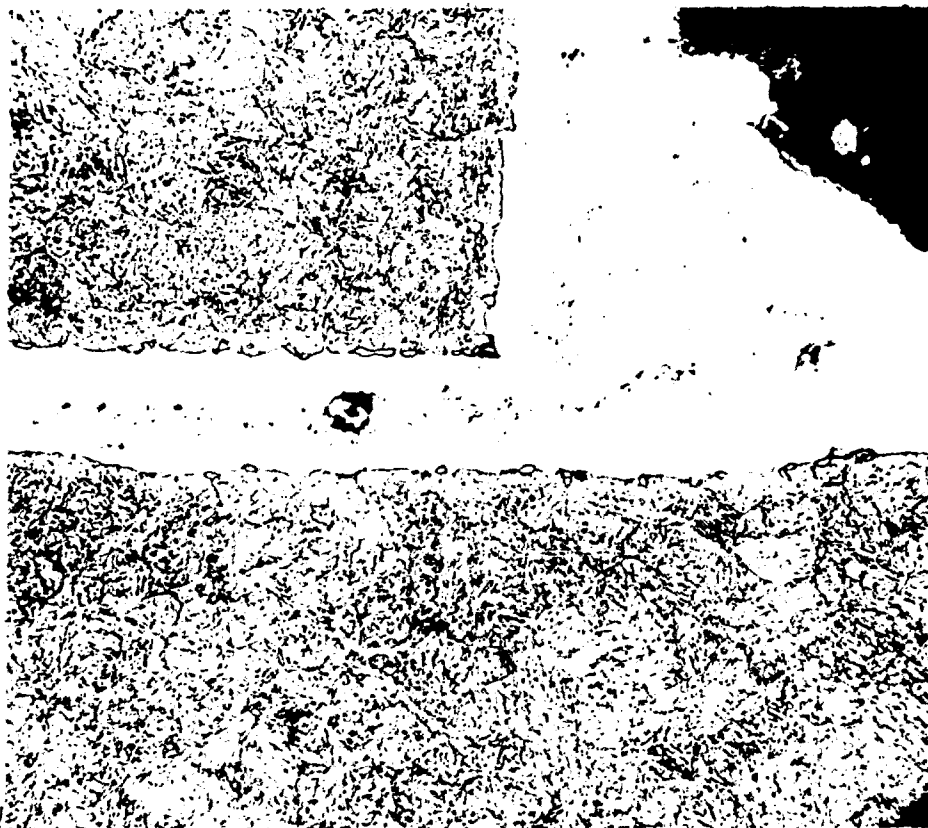
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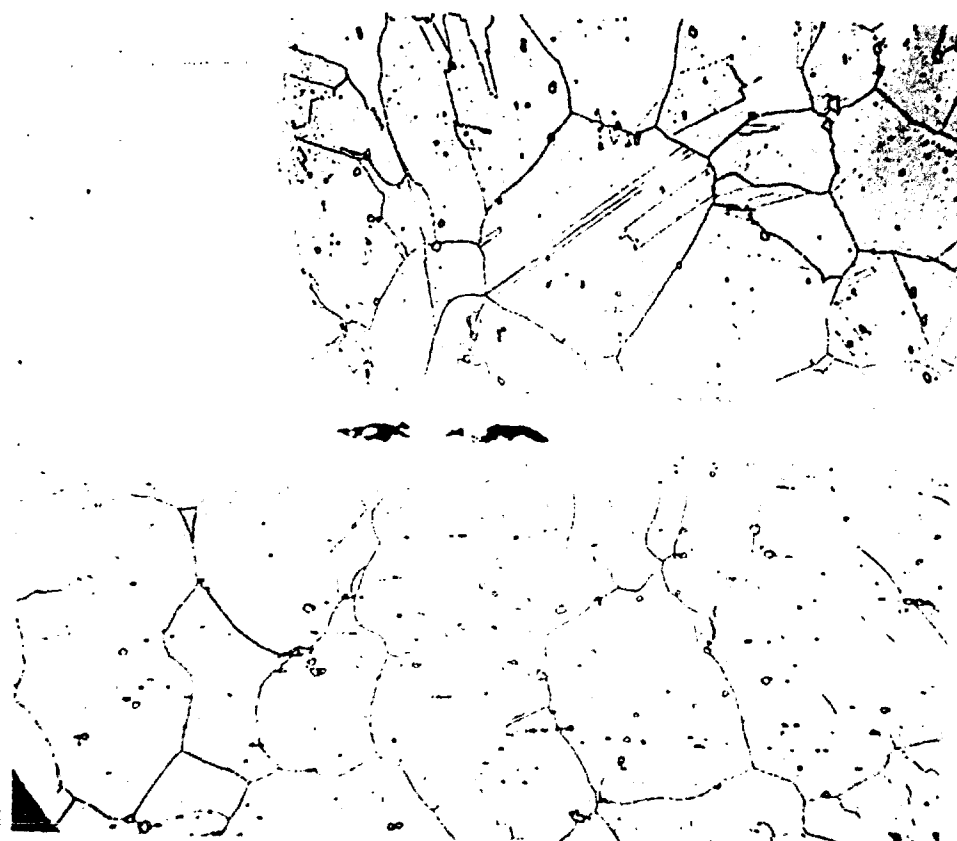
Mag. 250X

Vilella's Reagent - Etch

422 M brazed with Microbraz 50 brazing alloy  
impregnated with an organic binder.

Figure 10

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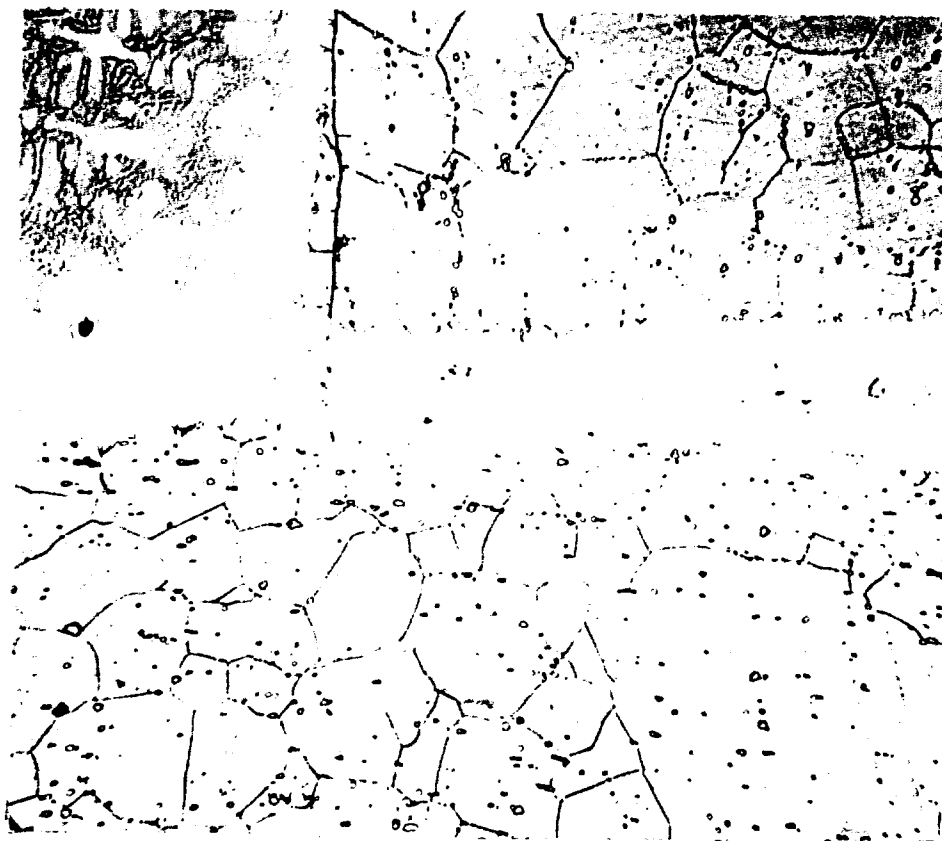
Mag. 250X

Etch - Electrolytic Oxalic Acid

M 252 brazed with 24% palladium, 55.2% nickel,  
9.8% chromium, 10% silicon brazing alloy.

Figure 11

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Mag. 250X

Etch - Electrolytic Oxalic Acid

GE 1610 (Rene 41) brazed with J 8100 brazing alloy.

Figure 12

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